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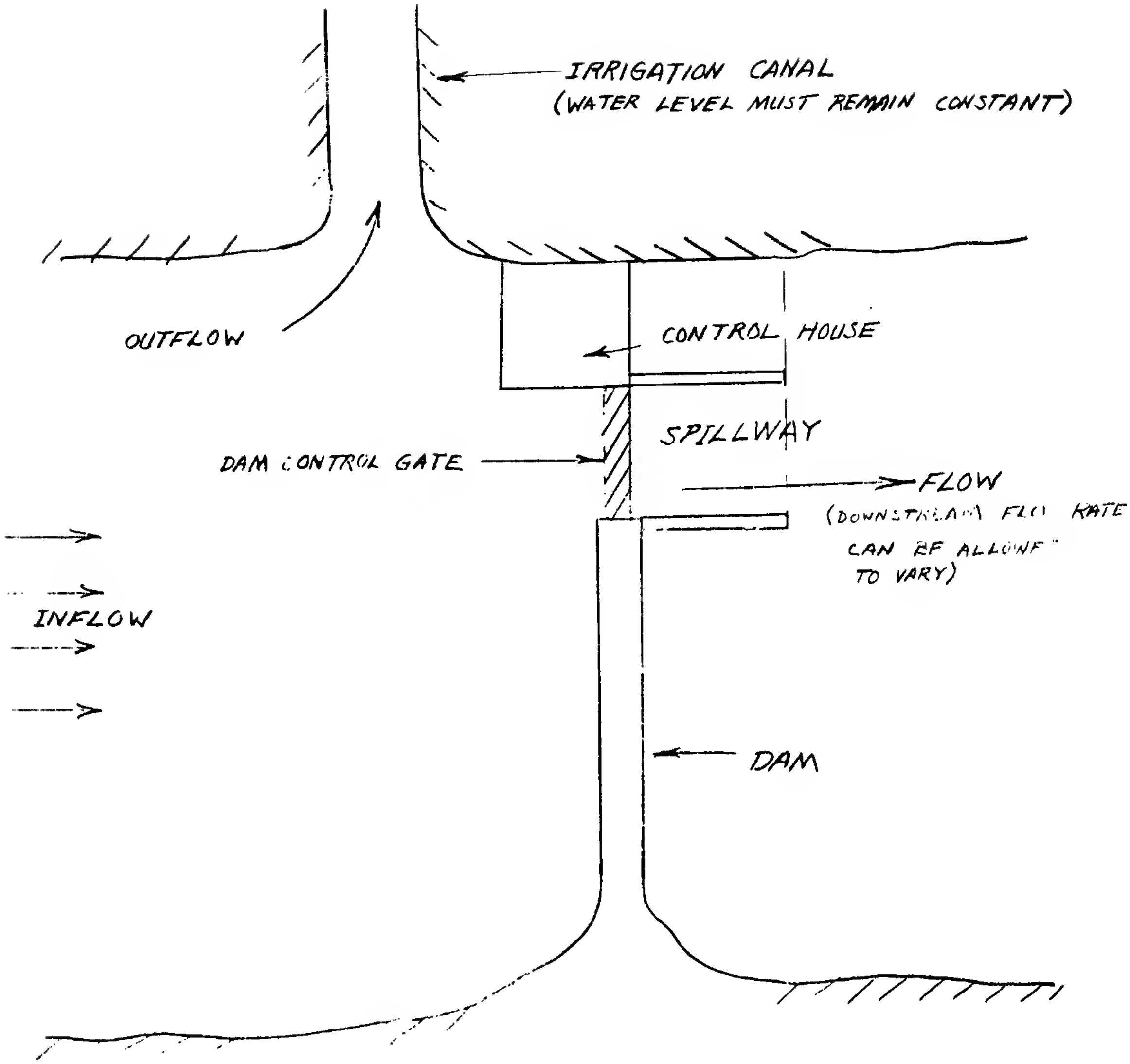
Hunting Problems of a Dam Control Gate

"It was my first day on the job, and I had only been at work for a couple of hours when my supervisor called me into his office for a conference," recalled Mr. Bill Clemens, a mechanical engineer in the Sacramento office of the U. S. Bureau of Reclamation. "He explained to me that the automatic gate control at the North Side Diversion Dam, near Orland, California, was 'hunting' badly and asked me if I'd try to find a way to stop it from doing this."

The control on the dam was float-operated and installed to keep the water level of the reservoir behind the dam constant. By tripping relays when the water level was above or below two control limits, the device increased or decreased the amount of water passing over the dam by opening or closing a regulating gate on the spillway (Exhibits 1, 1a). Bill's supervisor said the mechanism moved the gate too far in response to changes in the reservoir's water level, causing the water level periodically to rise above and fall below the control limits. The gate would respond to these "tides" by alternately opening and closing ("hunting"), and thereby reinforcing the oscillation.

Prepared in the Design Division of the Department of Mechanical Engineering by William J. Clemens under the direction of Karl H. Vesper with financial support from the National Science Foundation.



SCHEMATIC SKETCH OF NORTHSIDE DIVERSION DAM

Bureau of Reclamation

The Bureau of Reclamation is an agency of the United States government organized around the year 1900 to help develop water resources of 17 western states. It has designed and supervised construction of many irrigation systems, including dams, canals, pumping plants, and related distribution facilities. Most of the Bureau's projects provide flood control, irrigation water for farmlands, and municipal water for adjoining townships. These projects have included Hoover Dam on the Colorado River and the Grand Coulee Dam in Washington. Hydroelectric power is often sold to help defray costs of these projects.

In many of these distribution systems, canals carry irrigation water from storage reservoirs to points of distribution where local districts transport the water to customers via their own facilities. The canals carry water by gravity flow and are provided with "check gates" at intervals to keep the water level constant for any range of flows. These gates can be raised and lowered either manually or automatically to regulate flow. Diversion dams which feed some of the canals have similar gates, and it was with one of these that Bill was concerned.

The Assignment

Bill had just graduated from the University of California, Davis, and had reported to work in the Bureau's Division of Irrigation for the summer, when his supervisor, Mr. Terry Polley, gave him the automatic control problem. Mr. Polley explained that the Army Corps of Engineers had recently constructed a new "spillway"[1] with an automatically controlled gate on the North Side Diversion Dam, near Orland, California. This dam was a fairly small structure (being less than 40 feet high), built to divert water from Stony Creek, west of Orland, into some irrigation canals. Ever since the new spillway had been put into operation, he said, the automatic gate control had tended to "hunt". This caused the water level downstream from the dam to fluctuate so much that, according to reports, a person could see the water level movements as far as a mile below the dam. There was a chance that these water fluctuations might disturb the operation of the Glenn-Colusa Canal some distance below the dam. Terry asked Bill to look through what information he could find and see if anybody had tackled this problem before, and if they had, to see if their solution could be adapted to this situation. If it had not been taken care of before, he asked Bill to try to come up with a solution of his own.

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[1] spillway: a concrete "ramp" or tunnel built on most dams over or through which water not needed to maintain the reservoir surface elevation passes. See Exhibit 1a.

"Terry explained to me that the control used on this dam was the so-called 'Little Man' device that the Bureau has been using on its canals and diversion dams for a number of years," Bill recalled (see Exhibits 2a and 2b for one model of the "Little Man"). The "Little Man" has a float which senses changes in water level of the canal or reservoir on which it is installed. A steel tape or wire fastened to the float passes over a pulley and has a counterweight attached to its other end to keep it taut. This pulley is typically mounted on a shaft to which two cams are attached. Two limit switches are mounted above the cams so that when the water level rises above or falls below the control limits, one or the other is turned on. This starts an electric timer which turns on the a.c. gate hoist motor for small periods of time. When one of the switches is turned on, the timer turns the motor on for a few seconds then stops it. If the switch is still on, the timer waits a few minutes then turns on the gate motor for another few seconds. This cycle is repeated until the water is back within the control limits and the switch is turned off, at which point, the gate ceases to move. Depending on the switch activated, the timer either causes the motor to raise or lower the regulating gate. By changing the delay between gate movements (which is adjustable on most of the timers from 1-5 minutes), one can adjust the average speed that the gate moves up or down (i.e., the distance that it moves over the length of a timer cycle). "Terry told me that in a lot of places where the 'Little Man' is used, operators make this timer delay long to combat 'hunting'. I guess the operator who discovered this trick found with experience that it worked. The main disadvantage of doing this is that the gates aren't opened fast enough if the flow of water upstream of the gate is increased significantly."

Bill's Approach

"After I got this assignment," Bill continued, "I asked one of the other two men in the office where I could find some information on the 'Little Man' control. He didn't know exactly what the 'Little Man' might be filed under, but he showed me where our office filed copies of correspondence, project specifications, Designer's Operating Criteria[2], and even issues of the Bureau's monthly 'Irrigation Operations and Maintenance Bulletin', which is a publication that carries articles dealing with new ideas being used by the Bureau in its operations and maintenance activities. The one thing I found in our office files that did me the most good, was the Designer's Operating Criteria for the North Side Diversion Dam. It didn't give me much pure technical information, because it was written chiefly as a set of instructions to maintain the dam, but it did contain a wiring diagram of the control house which gave me a pretty good idea of how the timing mechanism worked (Exhibit 3). When I was first told about the 'Little Man', I got the impression that the Bureau only made use of it in this state (California), but after reading some of the 'Irrigation Operations and Maintenance Bulletins', I found that it was even in use on small canals up in Washington.

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[2] Designer's Operating Criteria -- a set of operating and maintenance instructions which the Bureau has made for each of its projects since about 1950.

"I thought of analyzing the 'Little Man's' response using some concepts from my M.E. 182 course (a junior level course entitled "Linear Systems Analysis"), and trying to see if I could stop the 'hunting' by merely changing some of the control's parameters," Bill said. "This would have been the logical thing to do if the 'Little Man' changed continuously with the water level, but its timer made the gate open and close in such a way that it would have been almost impossible to carry out the mathematics involved. So, I didn't even try a formal analysis, but looked at the operation of the control from an intuitive point of view, trying to 'get a feel' for how the 'Little Man' worked and what was wrong with it.

"I studied the wiring diagram for a while, tracing the timer and relay circuits to see if I could make any changes there, but I couldn't think of modifications that would have any effect on the 'hunting' problem. Then I started looking for changes I could make in the sensing mechanism.. All the existing 'Little Man' had was a pair of switches that told the timers and relays when the water level wasn't between two elevations. I talked the problem over with Terry, and he seemed to agree that the control's trouble probably was in the sensing mechanism. We studied the device for awhile, and decided it might help if we made the sensing part of the control more sophisticated, perhaps modifying it so that it could tell what was happening to the water level outside of the control limits.

"I had a couple of other assignments during those first few days; mainly ordering some plastic-coated drawings for use at one of our dams and reviewing some reports about a debris problem our Shasta field office was having at a small reservoir as the result of a recent storm. These jobs didn't seem to be too urgent, so I spent a few hours working on the 'Little Man' problem," Bill continued. "I spent most of my time 'doodling' on a piece of paper trying to organize my thoughts into some meaningful ideas. I had already reached the conclusion, because of my talks with Polley, that the existing control was 'hunting' because it kept opening or closing the control gate at a pretty constant rate, even when the water level was moving back (either rising or falling) to the control limits.

"While I was thinking about the problem, I remembered how Terry told me that some of the operators made the 'Little Man's' time delay long to combat 'hunting'," Bill recalled. "Somehow, this gave me the idea that making the average speed at which the gate opened or closed proportional to the difference between the actual water level and the control limits might help. This way, for large changes in flow, the gates would open fairly rapidly to let the water through, but as soon as the water level came back to near the control limits, the time delay would be long, allowing the water to reach some kind of equilibrium before the gates again moved."

Bill's First Proposal

Bill made a preliminary sketch of his modification to help him explain how it would work to his supervisor, Mr. Polley. He replaced the single timer in the "Little Man" (Exhibit 3) with two different timers. One timer determined how often the other timer was turned on. The second timer, in turn, determined the length of time that the gate hoist motor was turned on for each cycle of the first timer. The first timer was little more than a clock powered by a.d.c. motor. Bill reasoned that he could then vary the length of a timer cycle by changing the speed of the d.c. motor. If this speed was changed proportionately to the magnitude of the difference between the actual water level and the control limits, then the gate would open or close faster for large than for small changes in the water level. Bill thought this modification would allow the control to take care of sudden large changes in flow into the reservoir, but would still provide the benefits of having a long timer delay for normal small changes in flow.

To make the d.c. timer speed proportional to the size of the difference between the actual water level and the control limits, Bill proposed that rheostats be attached to the float pulley shaft as shown schematically in Exhibit 4. The cams represented here correspond to the existing cams on the conventional "Little Man" shown in Exhibit 2. The rheostats would be adjusted so that their resistances would decrease as the water level moved further away from the control limits. This would then increase the current going into the d.c. timer and cause it to make more cycles per hour than for small water level-control limit differences. Since the a.c. timer would run once every d.c. timer cycle and would raise or lower the gate the same amount per cycle, this modification would have the effect of opening or closing the gate faster for large water level-control limit differences than for small ones.

"I took my sketch into Terry to see if he thought it would be a satisfactory modification," Bill explained. "He studied it for awhile and said that he didn't think it would completely eliminate the 'Little Man's hunting'. He pointed out, for example, that if the water level was rising above the control limits, this device would open the control gate at smaller and smaller intervals until the water quit rising and began to fall. Since the water level would then still be above the control limits, however, the gate would continue to open until the water fell back within these limits. Terry felt that the extra distance the gate opened after the water had already begun to fall was the cause of the control's 'hunting' problem and if that portion of the gate's travel could be eliminated, then the problem would be solved.

"I also found out during my talk with Terry," continued Bill, "that a successful solution to the 'hunting' problem at the North Side Diversion Dam might have greater use than I had originally suspected. He pointed out that although this dam was a relatively minor structure and that a less satisfactory solution to the problem might be acceptable there, the 'Little Man' was very widely used and a successful modification on this small dam might be adopted on all of the Bureau's 'Little Men'. I later found out that, in some places, 'hunting' creates an even graver problem than I had encountered on this dam. For example, on a canal, when one gate starts to 'hunt' it causes those downstream of it to 'hunt' also, often at larger amplitudes. If you have very many of these gates in series, you can have tremendous waves downstream from the last gate."

After spending some more time at his desk thinking about the problem, reviewing what he had already found out about the "Little Man", Bill concluded that the best solution to the problem would be to make an accessory to the control that would sense when the water level direction changed; that is, when it stopped rising or falling and began to return to its normal level. He thought that it would then be pretty easy to incorporate this device in the present electrical circuit to cut the gate motors off when the water started to return to its control limits.

Bill's next step was to figure out what type of accessory would accomplish his objective and to make a rough sketch of it. This sketch wouldn't have to be any more refined than the one that he made to explain his rheostat idea, but would have to be clear enough to help him explain to his supervisor, Mr. Polley, how his new idea might work. As Bill phrased it, "I think it's better to go over your rough ideas with someone who is familiar with your problem before you spend a lot of time on the small refinements of your design. If you find out that your idea isn't as good as you first thought it was, you will have wasted a lot of time that you could better have spent doing something else."

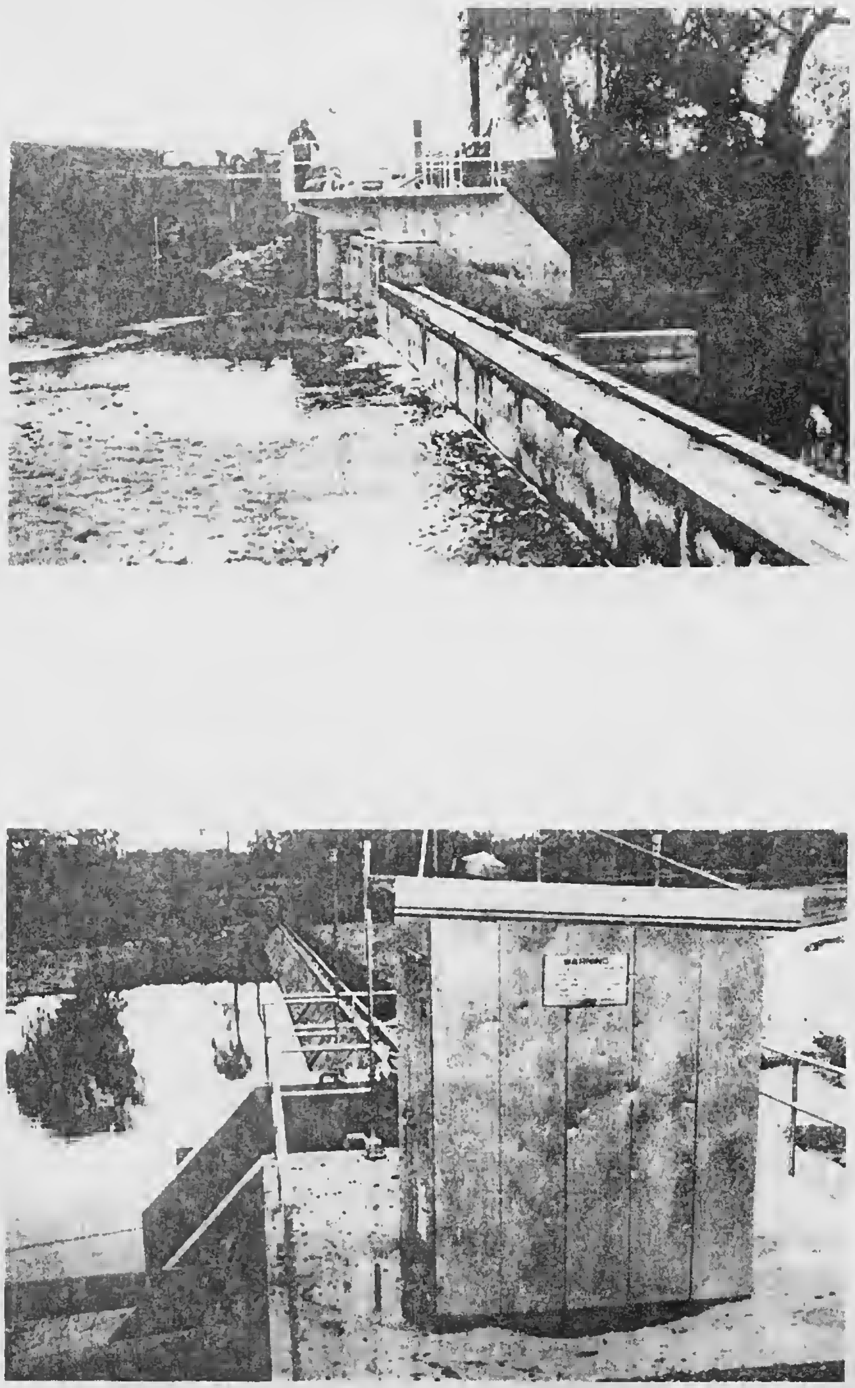


Exhibit 1 (continued). Two views of the North Side Diversion Dam showing the spillway structure and the control house.

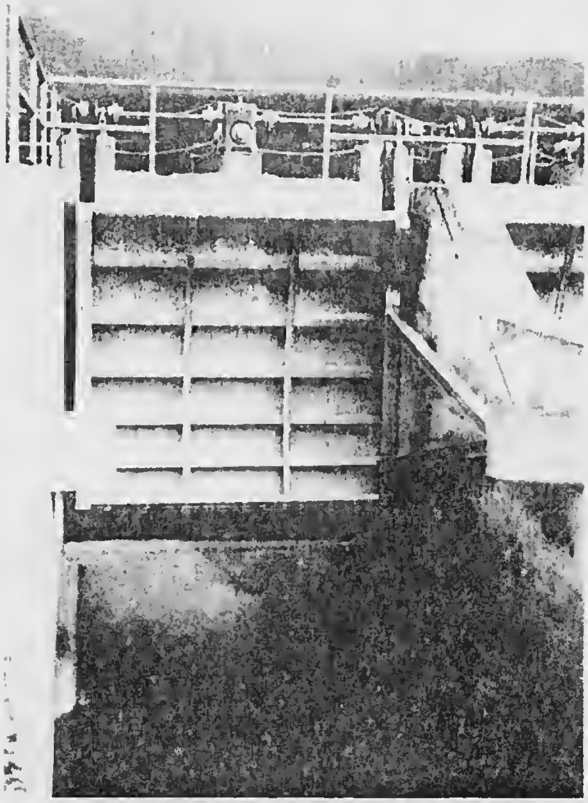
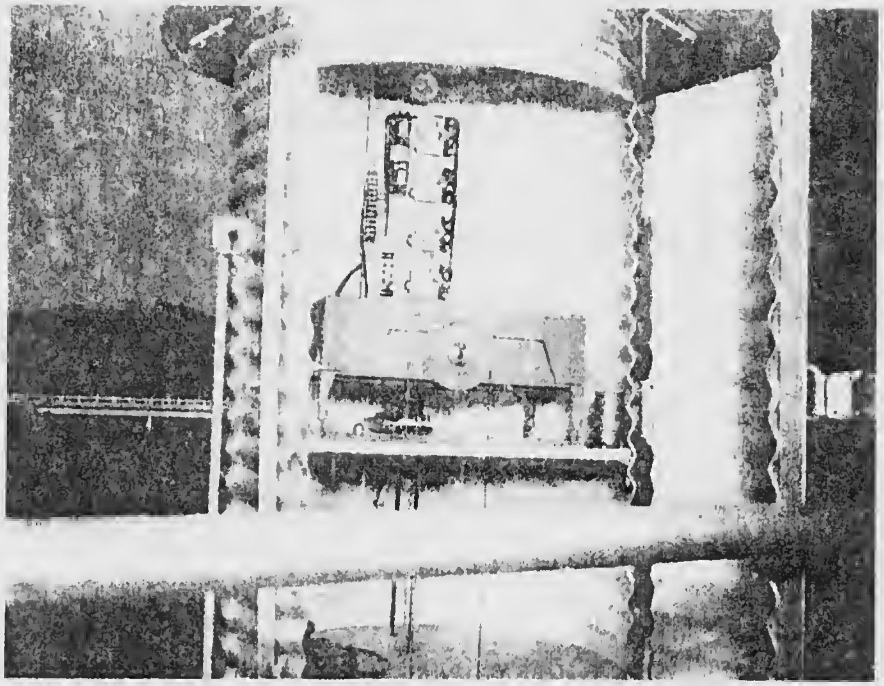
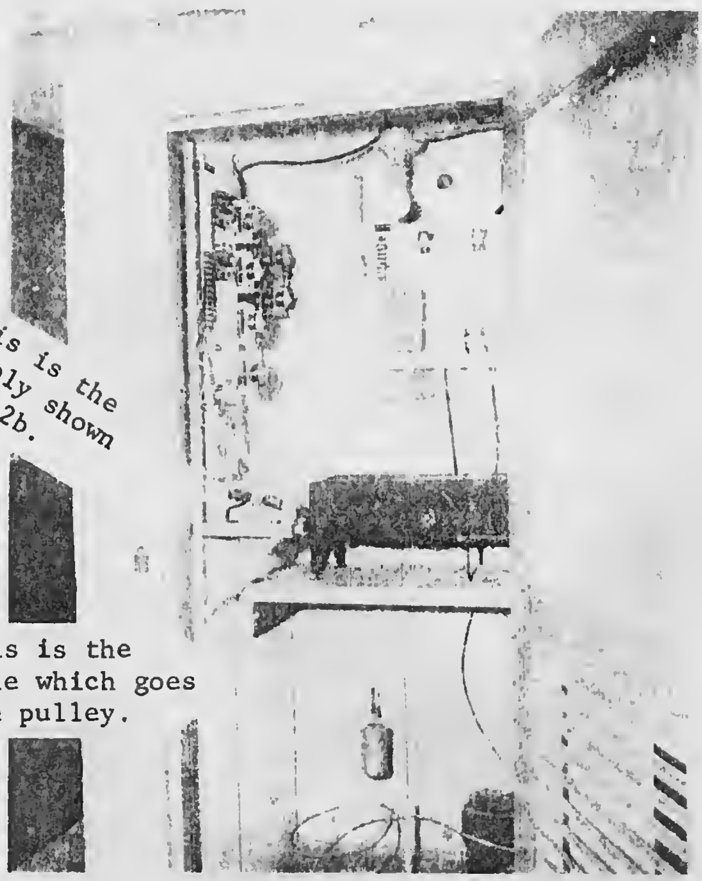


Exhibit 1a. A view looking upstream at a regulating gate similar to the one used at the North Side Diversion Dam. Bill never saw the gate at the North Side Diversion Dam, but he had seen this type of gate before. No water is flowing under this gate so part of the concrete spillway is visible.





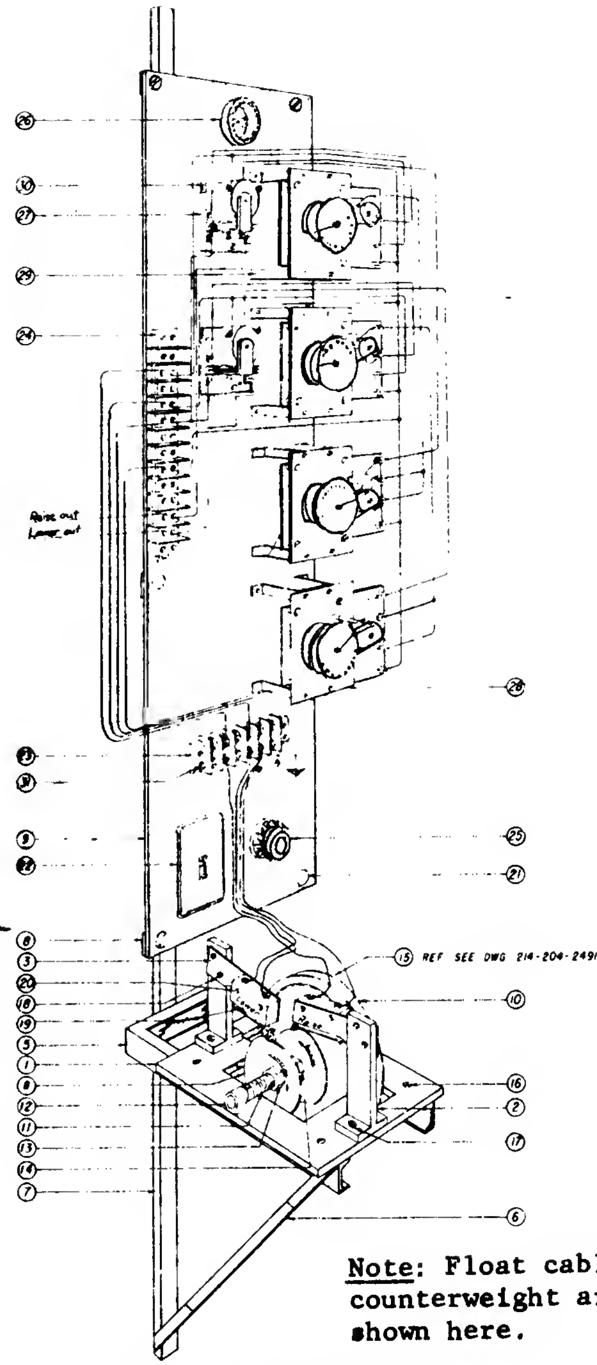
Note: This is the cam assembly shown in Exhibit 2b.

Note: This is the float cable which goes around the pulley.

Exhibit 2a. Two "checks" on the Friant-Kern Canal where the "Little Man" is being used. The units are mounted in metal or concrete shelters over their float-wells. The large boxes in each of the pictures are water level recorders. A more detailed drawing of one of these "Little Men" is shown in Exhibit 2b.

BILL OF MATERIAL				
Pce. No.	Name	Q.	Material	Used on Pce No.
1	Float Control Base Plate	1	1/4" Alum Pl	
2	Float Control Microswitch Bracket Support	2	1/4" Alum. Pl	
3	Float Control Microswitch Bracket	2	16 ga. Alum.	
4	Float Control Cam	2	16 ga. Alum	
5	Float Control Base	1	1" x 1/2" x 1/8" Chan Iron	
6	Float Control Base Support	1	1/8" x 3/4" Flat Iron	
7	Mounting Support	1	1" x 1/2" x 1/8" Chan. Iron	
8	Electrical Mounting Plate Support	3	1/8" x 3/4" Flat Iron	
9	Electrical Mounting Plate	1	1/8" Masonite	
Purchased Finished				
10	6" Dia Pulley	1	Cast Alum	5
11	1/2" x 5 1/2" Shaft (all thread)	1	Brass	5
12	1/2" Shaft Pillow & Nut	2	Copper	5
13	1/2" Hex Nut - 1/4" Thick	4	Brass	11
14	1/2" Hex Nut - 1/2" Thick	2	Brass	11
15	1/4" x 1 7/8" Stud & Sq Nut	1	Cast Iron	10
16	10-24 x 1/2" Rd Hd Scr	4	Brass	1
17	10-24 x 3/4" Rd Hd Scr & Nut	4	Brass	2
18	8-32 x 1/2" Rd Hd Scr, Nut & Lock Wash	8	Brass	3
19	Microswitch	2		3
20	6-32 x 1" Scr & Nut	8	Brass	19
21	1/4"-20 x 3/4" Rd Hd Scr, Nut & Lock Wash	10	Galv Iron	7 8 9
22	2 Way Switch	1		9
23	6 Wire Terminal Strip	1		9
24	12 Wire Terminal Strip	1		9
25	30 Amp Fuse Holder	1		9
26	Electric Light Socket	1		9
27	Double Pole Single Throw Relay	2		9
28	Syncronous Motor Time Switch	4		9
29	8-32 x 1/4" Rd Hd Scr	18	Galv Iron	28
30	8-32 x 1/2" Rd Hd Scr & Nut	8	Brass	27
31	8-32 x 3/4" Rd Hd Scr & Nut	8	Brass	23 & 24

Note: The part of the control below this line is the same as at the North Side Diversion Dam.



Note: Float cable and counterweight are not shown here.

PERSPECTIVE - AUTOMATIC GATE CONTROL

REFERENCE DRAWINGS

NOTE.
1 F... ...IL OF PARTS SEE DWG 214-204-2491
2 FOR BASE ASSEMBLY SEE DWG 214-204-2492
3 FOR ALTERNATE WIRING DIAGRAM SEE DWG 214-204-2493

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION REGION 2
CENTRAL VALLEY PROJECT-CALIF

ASSEMBLY
AUTOMATIC GATE CONTROL
AND
WIRING DIAGRAM

DRAWN: JEB - RAW ...... SUBMITTED ......
TRACED: RAW ...... RECOMMENDED ......
CHECKED: ...... APPROVED: ......
FRESNO, CALIFORNIA 8-15-55 | 214-228-249

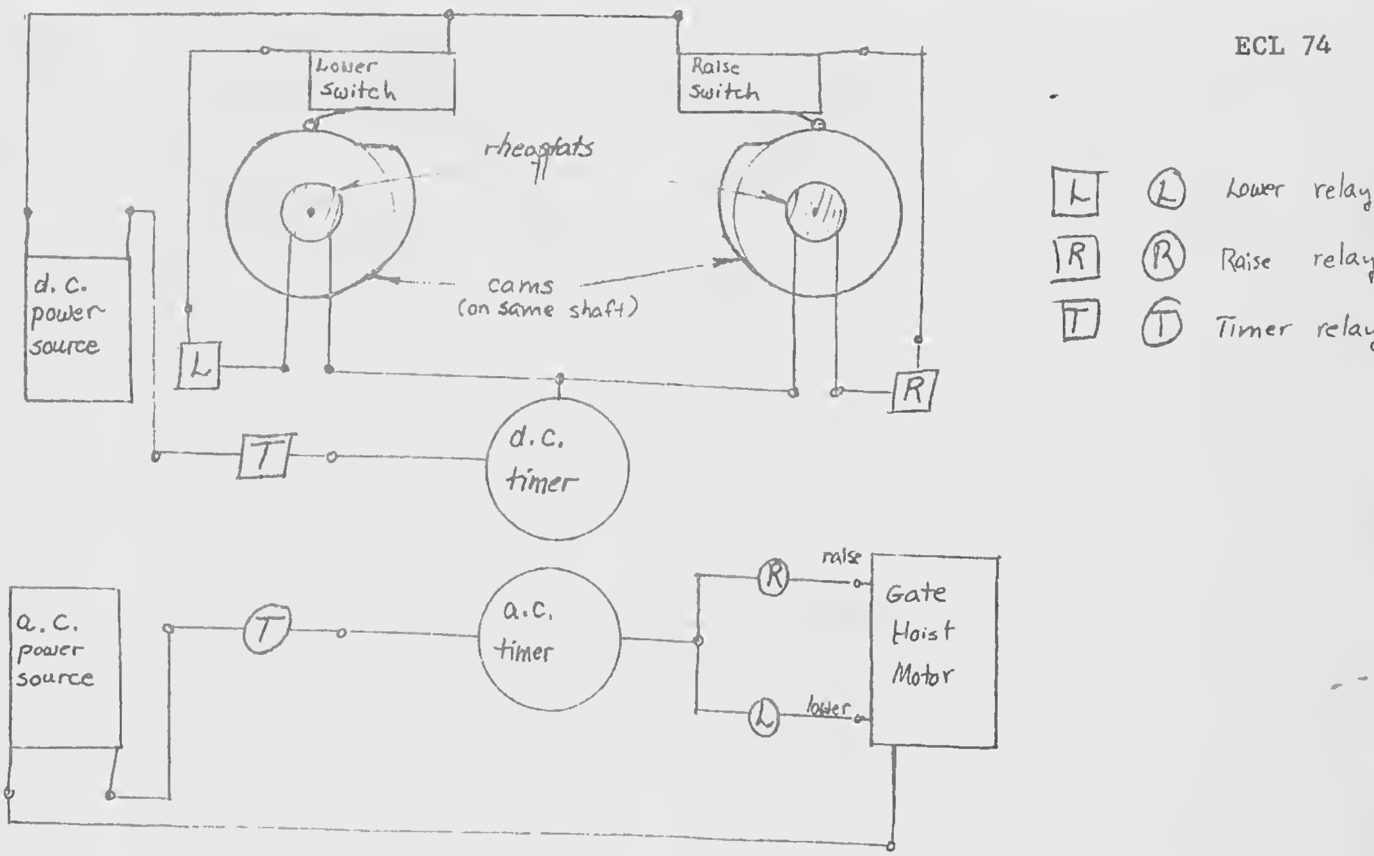
Revised 6-26-53 R.A.W. | Rev 3-12-54 J.E.B.

Exhibit 2b. One model of the "Little Man" control. This is not exactly the same as the control at the North Side Diversion Dam, but the part indicated by the note is the same.

Exhibit 3 (Continued)

Bill first looked at this drawing while he was thumbing through the Designer's Operating Criteria for the North Side Diversion Dam. "I noticed," he explained, "that the subtitle of the drawing was 'Electrical Layout and Control System' and thought that I could find out something about the 'Little Man' from it.

"The first thing that I noticed when I looked at the drawing was the subsection labeled '62M Cam Setting' (Casewriter's inserted letter A). I was a little confused by the type of notation used here, but tried to decipher it anyway to find out something about the timer operation. I noticed two schematic switches on the diagram labeled 'Level Detector' which I assumed represented the limit switches on the 'Little Man' control. I also noticed that there was a circle labeled RELAY-RAISE in series with one of these switches and a circle labeled RELAY-LOWER in series with the other switch. In addition, there were several branches of the diagram with components labeled the same as the circles I just mentioned; that is, labeled either CRL or CRR. The only way I could make any sense out of this diagram was to assume that when current flowed through one of the circles, all of the other components with the same label (e.g. CRL) would be opened or closed depending on whether the component was normally open or closed." For example, Bill's hypothesis would predict that if current flowed through 1, then 3 and 4 would be closed and 5 would be opened. When 3 and 4 were closed, the control would cycle and close the gate as described on page 3.

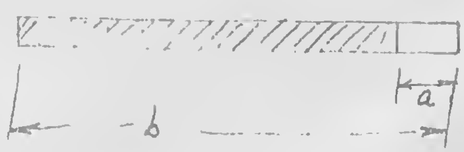


Relays: whenever current passes through the part of a relay indicated by $\boxed{A}$, the part of the relay indicated by Ⓐ is closed and current passes through it. Whenever current stops passing through $\boxed{A}$, Ⓐ opens.

d.c. timer: length of d.c. timer cycle governed by amount of d.c. current which is, in turn, governed by rheostats.

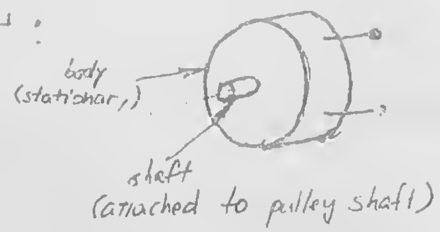
a.c. timer: turns gate hoist motor on for a few seconds at the end of each d.c. timer cycle.

timer cycle:



gate motor off
gate motor on
a : fixed time interval
b : variable time interval — governed by rheostats.

rheostat:



as shaft is turned in one direction, resistance increases;
as shaft is turned in other direction, resistance decreases.

Exhibit 4. Preliminary sketch of Bill's first proposal